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Experimental Study on the Temperature Distribution in an Emergency Staircase of High-rise Building

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Abstract

High-rise building safety has drawn public attention due to the occurrence of many catastrophic fires, to study the temperature distribution in the emergency staircase of a high-rise building in an accident, a set of experiments were conducted in a scaled building model. The window state in the staircase has a significant effect on the temperature distribution. When the window in the staircase is opened, the temperatures below the fire source floor almost maintain the ambient temperature during the whole period, but the temperatures above the fire source increase quickly and finally reach a quasi steady stage due to the stack effect. Moreover, if the doors below the fire source are opened, the fresh air flow into the staircase and decrease the temperature. On the contrary, when all windows in the staircase are closed, the doors state has a slight effect on the temperature distribution in the staircase. Because of the absence of the stack effect, the temperatures are low and the temperature attenuation coefficient β is larger.

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Keywords: temperature distribution, high-rise building, emergency staircase, stack effect

1. Introduction

During the past decades, many high-rise buildings have been constructed to accommodate the increasing population. The safety of these buildings has drawn public attention due to the occurrence of many

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catastrophic fires [1-3]. A notable example is the high-rise residential fire in Shanghai in 2010, causing 58 fatalities [4]. When a fire occurs in a high-rise building, the produced hot smoke will spread in the fire floor and flow into the emergency staircase, and then the temperatures in the staircase will increase and influence directly the building structure safety and personnel evacuation in the accidents. Therefore, it is worth investigating the temperature distribution characteristic in the emergency staircase of high-rise buildings.

Many researchers have studied temperature distribution in the shafts and staircases of high-rise building spaces in the past years [5-10], Benedict [5] investigated the temperature distribution in a 2.6 m tall square shaft with various cross sections and openings. Marshall [6] also investigated the smoke movement using a one-fifth scaled model of a five-storey staircase and obtained the typical temperature vertical distribution in the staircase. However the fire sources were located on the first ground in Benedict and Marshall experiments. Little attention has been focused on the temperature distribution in the staircase when the fire source is located on the other floors. Actually, the fire could occur on any floor of high-rise buildings. Moreover, the vents state on the lower floor would also affect the temperature distribution in the staircases. According to thus background, to study the temperature distribution in the staircase when the fire source is located in the middle floor of a high-rise building, a set of experiments were conducted in a scaled building model [7]. The temperatures in the emergency staircase were investigated.

2. Experiments

The 1/3 scaled building model [3, 8] consists of the staircase, atria and rooms, as shown in Fig. 1. This model with 12 floors is 12.2 m (high) × 2.6 m (long) ×1.5 m (wide). The left and front sidewalls of the building model are made of fire-resistant glass with 12 mm thick for observation, and the other parts are made of steel plate with 2 mm thick.

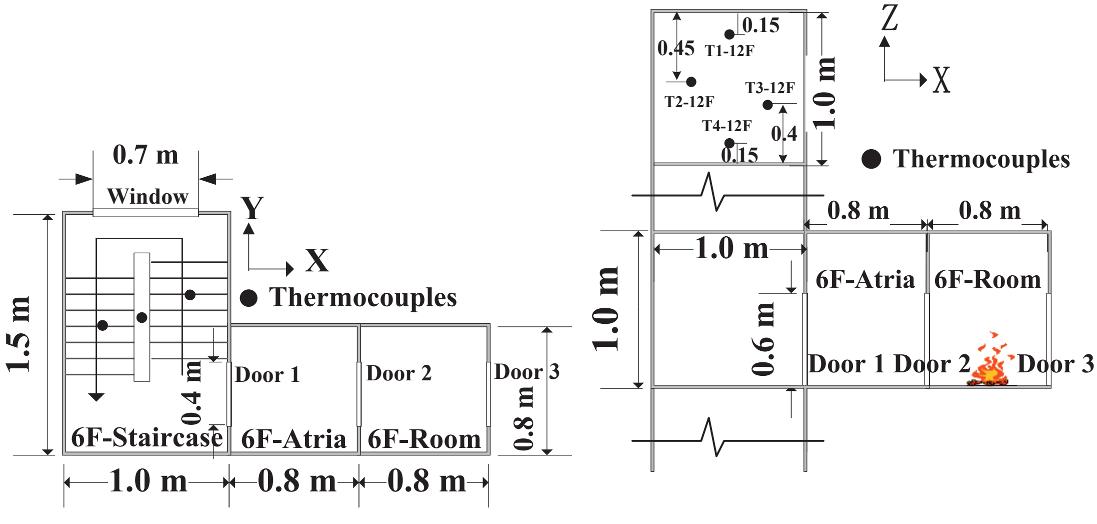

Fig. 1. Schematic of 1/3 scaled staircase building model [7] (a) top view; (b) side view

Heptane pool fire was used as the fire source and located in the center of the room on the 6th floor. The temperatures of hot smoke in the staircase were measured by 48 K-type fine wire thermocouples (1 mm in diameter). The locations of theses thermocouples are shown in Fig. 1. Agilent 34980A measurement unit was used to collect the temperature data [11]. The data were recorded at intervals of 1 s. In this series of experiments, Three doors on the 6th floor were always opened in all cases, while the window in the staircase on the 12th floor and the three doors on the 1st floor could be opened or closed. Ambient temperature was about 30 °C. Each case was repeated once, and the results showed that the repeatability was good.

3. Results and Discussion

After the fuel was ignited, the hot smoke produced by the fire source migrated to the atria and staircase through the door 1 and door 2 on the 6th floor, and flowed into the staircase. The hot smoke spread upward along vertical staircase and the temperatures in the staircase increased gradually, as shown in Fig. 2. When the window in the staircase on the 12th floor was opened, it can be seen from Fig. 2(a) that the 12th floor temperature (T1-12 Floor) arises suddenly at 150 s, which indicates that the hot smoke arrives the 12th floor at 150 s. Then the temperatures increase sequentially because of more hot smoke flow into the staircase. The 6th floor temperature (T1-6 Floor) reaches a maximum of 135 °C and the 12th floor temperature rises to 60 °C at 340 s, then the temperatures almost remain basically unchanged from 340 s to 410 s. While the temperatures below the 6th floor almost maintain a constant of 30 °C during the whole period owing to the absence of the hot smoke. When all the windows in the staircase were closed, it can be seen from Fig. 2(b) that the temperatures are relatively low. The 6th floor temperature reaches a maximum of 60 °C at 380 s in case 3, that is smaller than that in case 1. The 10th floor temperature begins to arise at 480 s, while the 11th floor and 12th floor temperatures always maintain the ambient temperature of 30 °C during the whole period, which indicates the smoke plume front arrives finally the 10th floor in case 3. Comparing the data in Fig. 2(a) and Fig. 2(b), it can be seen that the phenomenon is different in case 1 and case 3. The temperature rise is faster from 150 s to 350 s in case 1 than that in case 3. The temperatures finally reach a quasi steady stage in case 1, while not in case 3. The significant reason is that the stack effect occurs in the staircase when the 12th window is opened. The stack effect [12] is the air movement caused by the pressure difference which results from the temperature difference between inside hot air and outside cold air in vertical shafts. The fresh air is sucked into the lower floor and the hot air flows out from the upper floor owing to stack effect, which can enhance greatly the smoke vertical movement in the staircase, while the stack effect is absent when all the windows are closed in the staircase, the hot smoke only spread upward on the basis of thermal buoyancy, so the velocity of the hot smoke movement is slower, and the temperatures are lower.

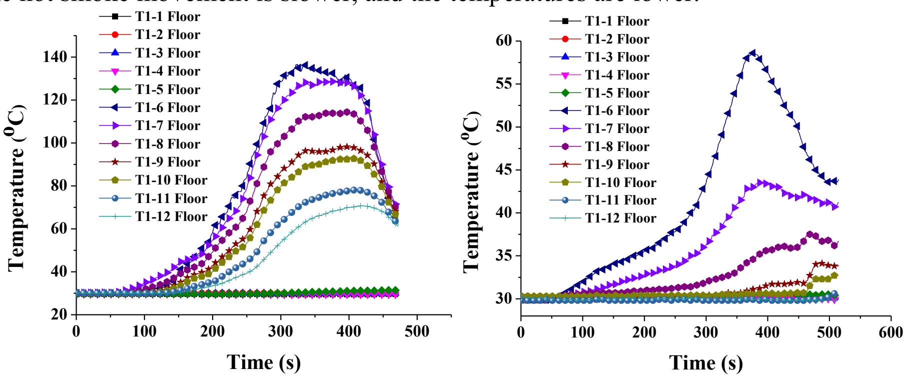

Fig. 2. Temperatures in the staircase versus time in different cases (a) case 1: the window in the staircase on the 12th floor was opened and the three doors on the 1st floor were closed; (b) case 3: all the windows in the staircase and the doors on the 1st floor were closed

To study the influence of the three doors on the 1st floor state on the temperature distribution in the staircase, the temperatures of hot smoke were also measured when the three doors on the 1st floor were opened, and the temperature distribution along vertical staircase at 360 s in different cases is shown in Fig. 3. When the window in the staircase on the 12th floor was opened, it can be seen that the three doors state has a significant effect on the temperature distribution in the staircase. The temperature is lower in case 2 when the doors are opened on the 1st floor. For example, the temperature is about 130 °C at 7 m high in case 2, while that is about 100 °C at 7 m high in case 1. The reason is that the cold air can flow into the staircase through the three doors opened on the 1st floor due to the stack effect, cooling the hot smoke temperatures. When all the windows in the staircase were closed, it can be seen that the three doors state has a slight effect on the temperature distribution in the staircase. Whether the doors on the 1st floor are opened or closed, the temperatures are almost the same at the same height in case 3 and case 4, because of the absence of the stack effect in enclosed staircase.

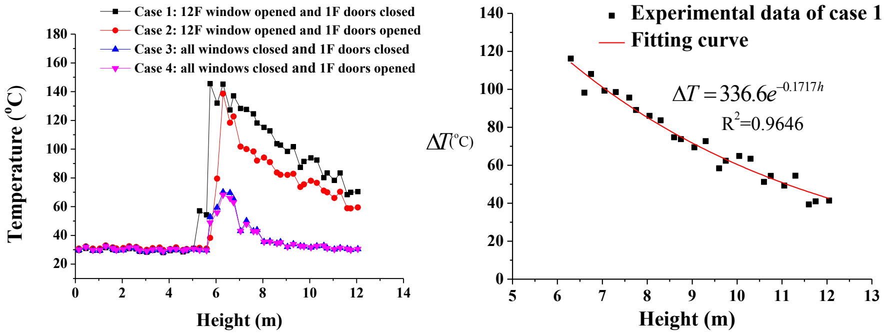

Fig. 3. (a) temperature distribution along vertical staircase at 360 s in different cases; (b) the calculated temperature attenuation coefficient β in case 1

Sun [8] suggested that the temperatures in staircase were found to exponentially decay with height in steady state, as shown in equations (1).

$$\Delta T = T_h - T_0 = Ae^{-\beta h} \tag{1}$$

where ΔT is the temperature difference between hot smoke in staircase and the ambient air, h is the height, T_h is smoke temperature in staircase at h, T_0 is temperature of the ambient air, β is temperature attenuation coefficient.

The calculated temperature attenuation coefficient β in case 1 is shown in Fig. 3(b), it can be seen that the temperatures in staircase decrease with the increasing height in case 1 and the experimental data are fitted according to equation (1). The calculated temperature attenuation coefficient β in case 1 is about 0.1717. Similarly, the temperature attenuation coefficient β was obtained in other cases, and β is about 0.2022, 0.8845, 0.8594 in case 2, case 3, case 4, respectively. According to the equation (1), the temperature attenuation coefficient β is larger, which means the temperatures decrease quickly in the staircase. Comparing the value of these cases, it can be seen that the temperature attenuation coefficient β is smaller in case 1 and case 2 when the window on the 12th floor is opened, which indicates the temperatures decrease slowly in the staircase, because the velocity of the upward smoke movement is quicker due to the stack effect. On the contrary, the temperature attenuation coefficient β is larger owing to the absence of the stack effect in case 3 and case 4 when all windows are closed in the staircase.

4. Conclusion

In this paper, to study the temperature distribution in the emergency staircase of a high-rise building, a set of experiments were conducted in a scaled building model. The main results are summarized as follows:

When the window in the staircase is opened, the temperatures below the fire source floor almost maintain the ambient temperature during the whole period, but the temperatures above the fire source increase quickly and finally reach a quasi steady stage due to the stack effect. Moreover, if the doors below the fire source are opened, the fresh air flow into the staircase and decrease the temperature. On the contrary, when all windows in the staircase are closed, the doors state has a slight effect on the temperature distribution in the staircase. Because of the absence of the stack effect, the temperatures are low and do not reach a quasi steady stage. In addition, the temperature attenuation coefficient β is larger.

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